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Bioaccumulation of Toxic Substances Associated with Dredging and Dredged Material Disposal

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16. ABSTRACT

A literature review of sediment bioassessment was conducted as the first step in the development of a more standardized and ecologically sound test procedure for evaluating sediment quality. Based on the review, the authors concluded that 1)a standardized laboratory bioassessment test should consistof flow-through exposure of at least 10 days duration using more than one aquatic organism including at least an infaunal benthic invertebrate and a fish species. 2) Before adoption of a laboratory sediment bioassessment procedure, the laboratory results should be evaluated by comparison with field conditions. 3) Most current sediment bioassessment regulatory tests measure acute toxicity or bioaccumulation. Development of tests to evaluate chronic, sublethal effects is needed.

17. KEY WORDS AND DOCUMENT ANALYSIS

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BIOACCUMULATION OF TOXIC SUBSTANCES ASSOCIATED WITH DREDGING AND DREDGED MATERIAL DISPOSAL

A LITERATURE REVIEW

by

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Final Report
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Project Officer

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FOREWORD

The Great Lakes National Program Office (GLNPO) of the United States Environmental Protection Agency was established in Region V, Chicago, to focus attention on the significant and complex natural resource represented by the Great Lakes.

GLNPO implements a multi-media environmental management program drawing on a wide range of expertise represented by universities, private firms, State, Federal, and Canadian governmental agencies, and the International Joint Commission. The goal of the GLNPO program is to develop programs, practices and technology necessary for a better understanding of the Great Lakes Basin ecosystem and to eliminate or reduce to the maximum extent practicable the discharge of pollutants into the Great Lakes system. GLNPO also coordinates U.S. actions in fulfillment of the Great Lakes Water Quality Agreement of 1978 between Canada and the United States of America.

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SECTION 1

INTRODUCTION

The annual movement of over 10 million cubic meters of sediment by dredging activities in the Great Lakes is potentially harmful to the biota of the Great Lakes, not only due to the physical disruption of the habitat associated with dredging and dredged material disposal, operation, but also the relocation and resuspension of sediments often contaminated with toxic organic and inorganic chemicals. Current regulations regarding approval for dredging activities require measurement of contaminant levels in the sediment and comparison of those levels with established criteria. These criteria need to be correlated with bioavailability and toxic effects of the chemicals. To date, however, no broadly applicable correlations have been defined. The lack of a definable relationship between levels of chemicals in the sediment and bioavailability of the chemicals has led to the proposal that bioassessment tests (including toxicity and bioaccumulation) be conducted for all proposed dredging operations; in fact, such procedures are currently being used for ocean dumping of dredged material. Laboratory studies have shown the potential bioavailability of both organic and inorganic contaminants from resuspended sediments, but the procedures used for bioaccumulation studies vary widely and little information is available relating the accumulation of contaminants by organisms to overall effects on the ecosystem.

SECTION 2

SUMMARY

Because of our interest in developing methods for testing the bioavailability of contaminants, particular attention was given to laboratory tests that measure bioaccumulation of toxic substances from sediment. Many of these laboratory tests demonstrated the capability of aquatic organisms to accumulate toxic substances from sediment (3, 17, 22, 32, 53, 59, 64, 66, 68, 83, 85, 106); however, the precise extent to which this accumulation can occur remains unclear. Reported bioconcentration factors

$$\left(BCF = \frac{\text{concentration in organisms}}{\text{concentration in sediment}} \quad \text{or} \quad \frac{\text{concentration in organisms}}{\text{concentration in water}}\right.$$

depending on test) have been quite variable and are often confusing due to differences in measurement technique. Results of contaminant analysis of sediments and organisms are either reported as wet weight or as dry weight concentrations. Due to the differing amounts of water that occurs in sediments and aquatic organisms, resulting BCFs can vary severalfold depending on the basis used for calculation. Routine reporting of contaminant levels in sediments and organisms as dry weight concentrations and calculation of resulting BCFs based on dry weight concentrations would eliminate the influence of water content and reduce the variability in reported BCFs.

An additional problem in interpreting the literature is that application of a BCF in bioaccumulation tests is not always indicative of the true accumulation potential. For example, tests with highly contaminated sediment (thus resulting in a large denominator in the BCF equation) may yield a low BCF even though statistically significant contaminant accumulation is occurring in the organism. Reported BCFs of less than one are therefore common in the literature even though bioaccumulation occurred in the test organism. Defining

the ratio $\left(\frac{\text{concentration in organism}}{\text{concentration in sediment}}\right)$ as a "bioaccumulation factor"

(BAF) rather than as a BCF (79, 106) improves the semantics of the problem, but the ultimate solution to the problem appears to involve using bioaccumulation tests that compare accumulation between organisms exposed to test sediment and organisms exposed to a control and/or reference sediment. This method of testing and reporting should produce results that have improved interpretative value in determining whether contaminants in test sediments are available for accumulation and, through proper selection of reference sediments, whether such accumulation would be expected to exceed "background levels" at specific study sites.

The majority of available literature describing bioaccumulation of contaminants is directed at organic compounds such as polychlorinated biphenyls (PCBs). Research on the bioaccumulation of metals from sediments, particularly in freshwater systems, is rather limited and the results tend to be conflicting. The difficulty in differentiating between normal background levels of metals in aquatic organisms (which can be quite variable) and

"contaminated" levels of metals further complicates the interpretation of results. Neff et al. (63) looked at accumulation of 10 metals using five different species of test organisms and observed statistically significant uptake in 25% of the tests. Seelye et al. (83) reported that perch accumulated Fe, As, Cr, Na, Hg, Zn, Cs, and Se from naturally contaminated sediments. However, Sherwood (85) exposed fish to contaminated sediments and observed no accumulation of metals, although PCB and DDT uptake did occur. Apparently, the bioavailability of metals from sediments is significantly influenced by several physical and chemical conditions in the sediments and water (86).

SECTION 3

CONCLUSIONS AND RECOMMENDATIONS

Based on our review of the literature, along with our personal experience with bioassessment tests and that of investigators at other research organizations with whom we have discussed the subject, we offer the following conclusions and recommendations for consideration in the development of standardized tests of toxicity and bioaccumulation. In so doing, we recognize that several tests currently employed by various organizations were not intended to measure bioaccumulation but instead emphasize acute toxicity. We further recognize that it may not be possible to develop a single standardized test applicable to all conditions and information needs. Nevertheless, we offer the following recommendations for developing more standardized and ecologically sound test procedures for evaluating sediment quality.

1. Static tests should be avoided. Mortality to test organisms has been attributed to low dissolved oxygen conditions during static tests, a condition that may not occur in field situations.

2. Elutriate testing appears to be of questionable value in evaluating sediment quality because few correlations have been measured between the toxicity of the sediments and results of elutriate tests. In addition, the elutriate test was designed to provide information on potential "water column effects" of dredged material disposal, however, the literature we reviewed did not identify any substantial irreversible effects of dredged material disposal on planktonic organisms at the disposal site.

3. Toxicity tests on the dissolved or suspended particulate phases of dredged material appear to be of questionable value due to the lack of serious "water column effects" as stated in 2. above. The results of acute toxicity tests on these phases exhibit poor precision in general, with high mortality to control organisms being reported. As a result, only extremely high mortality to the exposed organisms will be significantly different from controls.

4. In bioaccumulation studies, steady state concentrations have rarely been attained in less than 30 days. However, it may not be necessary to attain steady state to show bioaccumulation potential. Therefore, we recommend that the 10-day period be used as recommended in the EPA/COE Implementation Manual.

5. Whole sediment (unaltered dredged material) bioassays generally show low toxicity to benthic invertebrates and fish when exposures are 10 days or less. However, longer exposures (20-50 days) have resulted in mortality of benthic organisms approaching 50 percent. Use of whole sediment allows simultaneous collection of data on toxicity and bioaccumulation of contaminants by organisms, potentially reducing the number of tests required and therefore the total cost.

6. Availability of contaminants is greatly affected by physical characteristics of sediments such as particle size, distribution, total organic carbon, and mineral composition. Because the relationship between the physical and chemical characteristics of the sediment and bioavailability of contaminants is not well defined, a site by site evaluation of sediment quality is necessary except where contaminant levels are very low.

7. Contaminant concentrations based on dry weight should be used to calculate bioconcentration factors (BCFs) and bioaccumulation factors (BAFs) in order to eliminate the influence of variable and/or changing water content in the sediments and the organisms.

8. Bioaccumulation studies should emphasize comparing the accumulation (either as a rate or as total accumulation) among organisms exposed to test sediments and organisms exposed to a control and/or reference sediment rather than relying on a BCF or BAF calculated from exposure in the test sediment.

9. Some sublethal test parameters found in the dredging literature that show promise as tools for evaluating dredged material include: invertebrate reproductive success, growth abnormalities and pathology, avoidance behavior, invertebrate metabolic rate and swimming rate, and changes in enzyme activity (e.g., catylase).

10. Toxicity data from sediment bioassays using recirculating or static water conditions are less precise than data collected using flow-through bioassay systems. Therefore, the use of flow-through systems for both toxicity and bioaccumulation studies is recommended.

11. Organisms (including fish) allowed direct contact with sediments accumulate more contaminants than organisms not allowed direct contact with sediments. Therefore, exposure procedures that include provisions for contact between test organisms and both bedded and resuspended sediments would simulate worst-case conditions both at the dredging site and at the disposal site.

12. Bioassays conducted for ocean dumping of sediments currently must be conducted according to the methods described in EPA/CE Technical Committee, 1977 (Reference number 101 in Appendix A). Basically the protocol described in this manual includes three test procedures for laboratory bioassays: 1) acute toxicity test using elutriate water, 2) acute toxicity test using suspended particulate material from sediment; and 3) solid-phase bioassay, including a 10-day exposure of organisms to sediment with measurements of survival and bioaccumulation. The New York District of the Corps of Engineers has reported over 100 of these tests. Results from the static, acute-toxicity tests (procedure 1 and 2 above) were so variable that the personnel at the District have recommended eliminating these two procedures. Based on published results of toxicity tests we agree with this recommendation. In addition, solid-phase testing should be referred to as whole-sediment testing to insure that the fine sediment particles are not removed before the tests are conducted.

In summary, we recommend that: 1) A stronger link must be established between results of laboratory bioassessment tests and conditions at dredging and disposal sites. Results of laboratory bioaccumulation tests must be evaluated by comparisons with data obtained from organisms that were collected from the dredging and the disposal sites. 2) Since bioassessment procedures currently approved for use in regulating dredging include only measurements of toxicity (mortality) and/or bioaccumulation of toxic substances, we believe chronic bioassay tests should be developed for use in assessing sediment quality. 3) We recommend that work continue towards development of a single, standardized procedure for testing sediment quality. This procedure should include both measurements of toxicity and bioaccumulation in a flowing-water exposure system using more than one species of aquatic organism. Because the uptake of organic contaminants and metals is usually most rapid in benthic invertebrates that live in the sediments and are deposit feeders, we recommend use of such an organism. In addition to direct accumulation of contaminants, such as would take place in the benthic invertebrates, we believe that fish would provide an estimate of the relative amount of contaminant that may be released from the sediment and thus become available (either directly or indirectly) to the biota. When feasible, the procedure should include a species of fish that is ubiquitous in the watershed under consideration and known to feed, at least in part, on benthic invertebrates. The bioassays should be conducted with dredged material that is unaltered after collection from the area to be dredged. The organisms should be exposed to the sediments for 10 days or more under flowing water conditions. The presence of suspended solids in the test tanks would provide conditions similar to those at the dredging and disposal site during the actual dredging activity. The value of adding suspended solids during the exposure, though, must be tested before a recommendation can be made.

APPENDIX A

1. Armstrong, D. E., J. J. Perry, and D. E. Flatness. 1979. Availability of Pollutants Associated with Suspended or Settled River Sediments Which Gain Access to the Great Lakes. EPA-905/4-79-028, U.S. Environmental Protection Agency. 102 pp.

   Samples of suspended sediment from 5 Great Lakes rivers were collected and analyzed for total and available concentrations of Cu, Pb, and Zn. Two methods were used for measuring available metals: a hydroxylamine hydrochloride extraction, and a resin desorption. Available metals usually ranged between 25-45% of the total metals; however, in highly polluted samples (Menominee River), as much as 76% of the total metal concentration was estimated to be biologically available.

2. Auld, A. H., and J. R. Schubel. 1978. Effects of Suspended Sediment on Fish Eggs and Larvae: A Laboratory Assessment. Estuarine Coastal Mar. Sci., 6:153-164.

   "Eggs and larvae of 6 species of anadromous and estuarine fish indigenous to the Chesapeake Bay were exposed to concentrations of suspended sediment ranging from a few mg 1^{-1} to 1000 mg 1^{-1} to determine the effects of different concentrations on hatching success and short term survival. The egg experiments indicated that concentrations of up to 1000 mg 1^{-1} did not significantly affect the hatching success of yellow perch, blueback herring, alewife or American shad eggs. Concentrations of 1000 mg 1^{-1} significantly reduced ($P<0.05$) the hatching success of white perch and striped bass, but lower concentrations did not.

   Experiments with larvae indicated that concentrations of $\geq$ 500 mg 1^{-1} significantly reduced ($P<0.05$) the survival of striped and yellow perch larvae exposed for 48-96 h. American shad larvae appeared to be less tolerant than the other two species tested. Concentrations $\geq$ 100 mg 1^{-1} significantly reduced the survival of shad larvae continuously exposed for 96 h.

   The significance of these results are discussed relative to natural and man-induced changes in sediment loading of estuaries." (author abstract)

3. Bahnick, D. A., W. A. Swenson, T. P. Markee, D. J. Call, C. A. Anderson, and R. T. Morris. 1981. Development of Bioassay Procedures for Defining Pollution of Harbor Sediments. Part I. CLSES Contract Publication No. 56. Center for Lake Superior Environmental Studies, University of Wisconsin, Superior.

   Laboratory studies were conducted measuring toxicity and bioaccumulation, including measurements of acute toxicity tests using Daphnia magna, cough frequencies using bluegills, and bioaccumulation potential using Hexagenia limbata and chironomids. Metals, PCBs, PAHs, and DDT were measured in sediment and tissue samples and sediments were screened for organic contaminants using liquid chromatography procedures. Acute toxicity tests and bioaccumulation tests were conducted for 96 hours using either static or recirculating test conditions. Test results for the 96-hour toxicity test were variable and few differences were measured

between exposed and control organism survival. There were a few correlations between survival and chemical content of the sediments, but no consistent correlations were found between different organisms. The authors state that results of the acute toxicity tests showed sediments from more industrialized areas were more toxic than were those from less industrialized areas.

4. Beasley, T. M., and S. W. Fowler. 1976. Plutonium and Americium: Uptake from Contaminated Sediments by the Polychaete Nereis diversicolor. Mar. Biol., 38:95-100.

   The polychaete Nereis diversicolor was exposed in the laboratory to sediments naturally contaminated with plutonium and americium. Sediments collected near the Marshall Islands were contaminated by an atomic test and sediments collected from the Irish sea were contaminated from a nuclear fuel reprocessing plant. Sediments were vigorously rinsed with clean sea water prior to introduction of the polychaetes. Worms accumulated about 0.5% of the sediment concentration of both elements with a preference for plutonium. Tests were run for 40 and 225 days.

5. Birge, W. J., J. A. Black, A. G. Westerman, P. C. Francis, and J. E. Hudson. 1977. Embryopathic Effects of Waterborne and Sediment-Accumulated Cadmium, Mercury, and Zinc on Reproduction and Survival of Fish and Amphibian Populations in Kentucky. Res. Rep. No. 100, University of Kentucky Water Resources Research Institute, January 1977. 28 pp.

   Laboratory experiments were conducted to test the effects of contaminated sediments on successful hatching of eggs of rainbow trout, goldfish, and narrow-mouthed toad. Both contaminated and clean sediments were collected from the Kentucky River system and clean sediments were spiked with varying levels of Hg, Cd, or Zn. Eyed rainbow trout eggs and newly fertilized goldfish and toad eggs were hatched in a static bioassay system with sediment and clean water. Reduced survival to hatching and four days post-hatch was observed in all species at the lowest metal concentrations tested: 0.15, 1.34, and 104.6 µg/g for Hg, Cd, and Zn, respectively.

6. Bissonnette, P. 1977. Extent of Mercury and Lead Uptake from Lake Sediments by Chironomids. In: Biological Implications of Metals in the Environment, Energy Research and Development Administration, June 1977. pp. 609-622. (available from NTIS).

   Samples of sediments and chironomids were collected monthly for one year from four freshwater lakes in western Washington and analyzed for mercury and lead. Chironomids accumulated both metals to higher levels than the surrounding sediment for both metals. No direct correlation was observed, however, between metal concentrations in sediments and organisms.

7. Boddington, M. J., A. S. W. DeFreitas, and D. R. Miller. 1979. The Effect of Benthic Invertebrates on the Clearance of Mercury from Sediments. Ecotox. and Environ. Safety, 3:236-244.

   Tubificid worms were capable of removing mercury from artificially spiked (Hg) freshwater sediments in a laboratory study. The rate of mercury loss from sediments was dependent on worm density.

8. Brannon, J. M. 1978. Evaluation of Dredged Material Pollution Potential. Tech. Rep. DS-78-6, U.S. Army Engineers Waterways Experiment Station, Vicksburg, Mississippi, August 1978. 39 pp.

   This report summarizes the results of seven Dredged Material Research Program (DMRP) reports. Five of these reports are reviewed separately in the bibliography. The author's conclusions for this synthesis report are as follows:

   "The short term impact of dredged material on water quality and aquatic organisms is related to the concentration of chemically mobile, readily available contaminants rather than the total concentration. ...The short term chemical and biological impacts of dredging and disposal have generally been minimal.

   Longer term impacts of dredged material on water quality have generally been slight and can be evaluated by means of the Elutriate Test and analysis of the mobile forms of sediment contaminants. No significantly long term increase in water column contaminant concentrations has been observed at any aquatic disposal field site. The greatest hazard of dredged material disposal is the potential effect of the material on benthic organisms." (author abstract)

9. Brannon, J. M., R. M. Engler, J. R. Rose, P. G. Hunt, and I. Smith. 1976. Selective Analytical Partitioning of Sediments to Evaluate Potential Mobility of Chemical Constituents During Dredging and Disposal Operations. Tech. Rep. 76-7, U.S. Army Engineers Waterways Experiment Station, Vicksburg, Mississippi, December 1976. 176 pp.

   Chemical analyses were performed on sediments collected from freshwater (Ohio), estuarine (Alabama), and saltwater (Connecticut) environments. Sediments were divided into several phases; those dissolved: 1) in interstitial water, 2) adsorbed on sediment (exchangeable), 3) occluded or co-precipitated with iron and manganese oxide and hydroxide partitions (easily reducible), 4) bound in organic matter and precipitated as sulfide salts (organic and sulfide), and 5) found in the mineral crystalline lattice (residual). Standard elutriate tests were also performed. No correlation was observed between total metal content of sediment and metal concentrations in the standard elutriate. Correlations were observed, however, between metal and nutrient concentrations in the elutriate and their concentrations in the first three sediment phases. These three phases are thought to be the most mobile in the environment.

10. Brewer, G. D. 1976. Resuspended Sediment Elutriate Studies on the Northern Anchovy. In: Marine Studies of San Pedro Bay, California. Part 11, Potential Effects on the Biota of Outer Los Angeles Harbor, Toxicity Bioassay and Recolonization Studies, D. F. Soule and M. Oguri, eds. University of Southern California, Office of Sea Grant Programs, Allen Hancock Foundation, Harbor Environmental Projects. pp. 15-32.

"Samples of sediment from three locations in the Los Angeles-Long Beach Harbors and elutriates resulting from resuspension were assayed for heavy metals, pesticides, and other pollutants. Juvenile and adult northern anchovy (Engraulis mordax) were exposed to sediment elutriates prepared from seawater-sediment ratios between 4:1 and 100:1 for periods up to fourteen days. Toxicity varied between the three sediment samples; acute oxygen depletion was suspected as the cause of mortality. Analyses of muscle, gonad, gill, and liver tissues for silver, cadmium, chromium, copper, iron, manganese, nickel, lead and zinc from control and elutriate-exposed fish showed high levels of cadmium and zinc in fish exposed to the resuspended sediments. However, the small sample size precludes any conclusions regarding the rapid uptake of heavy metals. Sediment elutriate which had been stored for two weeks was not toxic to anchovy embryos and larvae." (author abstract)

11. Bryan, G. W., and L. G. Hummerstone. 1971. Adaptation of the Polychaete Nereis diversicolor to Estuarine Sediments Containing High Concentrations of Heavy Metals: I. General Observations and Adaptation to Copper. J. Mar. Biol. Assoc. U. K., 51:845-863.

Sediments and polychaetes collected from estuaries in southwest England and varying in the amount of copper pollution were analyzed for copper. Results showed a correlation in copper concentration between sediment and worms (after gut clearance). Toxicity testing showed worms in highly polluted sediments developed a resistance to copper.

12. Buikema, A. L., Jr., C. L. Rutherford, and J. Cairns, Jr. 1980. Screening Sediments for Potential Toxicity by In Vitro Enzyme Inhibition. In: Contaminants and Sediments, Vol. 1, R. A. Baker, ed. Ann Arbor Sciences, Ann Arbor, Michigan. pp. 463-476.

Laboratory bioassays were conducted with Dapnia magna and Hexagenia limbata under static-conditions in which Daphnia were suspended over sediments in beakers and Hexagenia nymphs were allowed to burrow into the sediments. Tests were conducted for 24 to 96 hours using sediments from seven locations in Lake Superior near Duluth, Minnesota. In vitro enzyme tests with four enzymes were also conducted. Toxicity and enzyme activities were measured using treated (chemically leached) and untreated sediments containing elevated levels of metals. Correlations were examined for sediment particle size, toxicity, and enzyme activity. Results show a negative correlation between metal content of sediment and particle size and also between percent inhibition of catalase activity and particle size. Correlations between percent survival of Daphnia or Hexagenia and sediment particle size show that fine sediments were lethal, independent of their metal content.

13. Canter, L. W., E. H. Klehr, J. W. Laguros, L. E. Streebin, G. D. Miller, and D. R. Cornell. 1977. An Assessment of Problems Associated with Evaluating the Physical, Chemical and Biological Impacts of Discharging Fill Material. Tech. Rep. D-77-29, U.S. Army Engineers Waterways Experiment Station, Vicksburg, Mississippi, December 1977. 236 pp.

"...This study focused on problems associated with evaluating environmental changes resulting from fill material discharges. A weighted-rankings technique was used to established priorities of permitting (administrative) concerns and technical deficiencies...

A literature survey was conducted to determine technical deficiencies. Potential physical impacts found include changes in infiltration and flow regimes, destruction/alteration of natural or man-made habitats, and creation of habitats. Chemical impacts were found to result from the release of suspended solids, organics, nutrients, and toxic substances. Biological impacts ranged from physical barriers to fish migration to complete "smothering" of entire wetland areas. The effects of leachates on aquatic biota were found to be complex and diverse, ranging from no measurable changes to acute toxicity. Technical research needs identified in decreasing priority include studies on impact quantification and modeling, verification of predicted long-term impacts, basic chemical and biological interactions and effects, applicability of dredged material disposal findings, characterization of wetlands, and magnitude of fill discharge operations." (author abstract)

14. Cardwell, R. D., C. E. Woelke, M. I. Carr, and E. W. Sanborn. 1976. Sediment and Elutriate Toxicity to Oyster Larvae. In: Dredging and Its Environmental Effects, P. A. Krenkel, J. Harrison, and J. C. Burdick III, eds. Amer. Soc. of Civil Engineers, New York, New York. pp. 684-718.

Acute toxicity tests were conducted with oyster (Crassostrea gigas) embryos (2 hours old) in the laboratory using sediments and elutriates from Grays Harbor, Washington. Deleterious effects were observed for natural sediments and sediment homologues at less than 0.1 g dry wt/l; however, no toxicity was observed in elutriates diluted by 50%. Mortality was attributed to a combination of mechanical and chemical factors.

15. Chamberlain, D. W. 1976. Effects of Los Angeles Harbor Sediment Elutriate on the California Killifish Fundulus parvipinnis, and White Croaker, Genyonemus lineatus. In: Marine Studies of San Pedro Bay, California. Part 11, Potential Effects on the Biota of Outer Los Angeles Harbor, Toxicity, Bioassay and Recolonization Studies, D. F. Soule and M. Oguri, eds. University of Southern California, Office of Sea Grant Programs, Allen Hancock Foundation, Harbor Environmental Projects. pp. 33-48.

Static 96-h bioassays conducted in the laboratory with elutriates of sediments collected from Los Angeles Harbor showed no significant mortality to killifish or croaker. Croaker held in elutriates for 28

days showed bioaccumulation of some metals compared to control fish. Concentration of Zn, Pb, Cr, and Cd in exposed fish were twice as high as those in control fish.

16. Chu-Fa, T., J. Welch, K. Chang, J. Shaeffer, and L. E. Cronin. 1979. Bioassay of Baltimore Harbor Sediments. Estuaries, 2(3):141-153.

Laboratory bioassays were performed with two species of fish, mummichogs (Fundulus heteroclitus) and spot (Leistomus xanthurus) and one mollusc (Mya arenaria), which were exposed in static systems to a series of concentrations of suspended sediment for 48 hours. Sediments were analyzed for Pb, Cr, Zn, Ca, As, PCBs, and hexane extracts. Median survival times decreased with increasing suspended sediment concentration. The relationship observed permits use of mummichog data to index gross toxicity of sediments throughout the harbor. Comparison of TLm values with benthic species diversity permitted zoning of the entire harbor into zones of high, moderate, and low toxicity.

17. Courtney, W. A. M., and W. J. Langston. 1980. Accumulation of Polychlorinated Biphenyls in Turbot (Scophthalmus maximus) from Seawater Sediments and Food. Helgol. Wiss. Meeresunters, 33:333-339.

Juvenile turbot were held in the laboratory for 15 days in laboratory aquaria containing sandy sediments spiked with PCBs. Turbot readily accumulated PCBs with concentrations in muscle reaching 2, 59, and 43 µg/g in sediments containing 1, 60, or 100 µg/g respectively. Concentrations of PCB in liver were 3 to 11 times greater than that in muscle.

18. DeCoursey, P. J., and W. B. Vernberg. 1975. The Effect of Dredging in a Polluted Estuary on the Physiology of Larval Zooplankton. Water Res., 9:149-154.

Laboratory bioassays were conducted with water samples collected from a dredging site, downstream from the dredging site, and from 3 locations within a diked disposal site in Charleston Harbor (South Carolina). Because of changing salinities, Daphnia (freshwater), Paleomonetes and Polydora (saltwater) species were tested for survival, metabolic rate, and swimming rate. Water from all sites was more toxic than control water, and water from the disposal site was most toxic. Decreases in metabolic rate and swimming activity were also observed in organisms exposed to test water when compared to controls. Disposal site water again had the greatest effect.

19. DiSalvo, L. H., H. E. Guard, N. D. Hirsch, and J. Ng. 1977. Assessment and Significance of Sediment Associated Oil and Grease in Aquatic Environments. Tech. Rep. D-77-26, U.S. Army Engineers Waterways Experiment Station, Vicksburg, Mississippi, November 1977. 148 pp.

Laboratory studies were conducted with mussels (Mytilus edulis), crabs (Hemigrapsus oregonensis), snails (Acanthina spirata), and freshwater clams (Corbicula sp.), which were exposed for up to 30 days to sediment contaminated with oil and grease. Sediments contaminated with 2000 ppm hydrocarbons produced about 50 to 70 ppm in mussels and crabs. The analytical procedure for hydrocarbons in tissue included a saponification procedure. Mortality was low in all tests for up to 30 days. The report is not clear as to exactly what chemicals were included in the analyses of total hydrocarbons.

20. Durant, C. J., and R. J. Reimold. 1972. Effects of Estuarine Dredging of Toxaphene-Contaminated Sediments in Terry Creek, Brunswick, Georgia, 1971. Pestic. Monitor. J., 6(2):94-96.

A field study was conducted examining the concentration of toxaphene in oysters before and after dredging heavily contaminated sediments in an estuarine creek. No increase in toxaphene concentration in already contaminated oysters (3.3 µg/g) was observed. Toxaphene in sediment ranged from 2.9 to 1,858.3 µg/g.

21. Duyvejonck, J. 1977. Distribution and Movements of Fishes in a Small Stream. Trans. Ill. State Acad. Sci. 70(2):212.

Evidence suggests that dredging disrupts habitat favored by some species of fish and that they do not readily return to such areas. This was an abstract of a paper presented in 1977 at a joint meeting of the Illinois and Missouri Academies of Sciences.

22. Elder, D. L., S. W. Fowler, and G. G. Polikarpov. 1979. Remobilization of Sediment Associated PCBs by the Worm Nereis diversicolor. Bull. Environ. Contam. Toxicol., 21:448-452.

Laboratory studies were conducted to study PCB uptake and loss by Nereis diversicolor using spiked sediment as a PCB source. Worms were placed directly in sediments under flowing seawater, sampled periodically (guts were purged of sediments), and analyzed for PCBs. Uptake phase of the tests lasted for 120 days and the elimination phase lasted 60 days. Substantial accumulation of PCBs took place, reaching a steady-state concentration after about 40-60 days. The biological half-time was calculated for this experiment to be 27 days. The authors conclude that PCB compounds in the sediment cannot be considered as being isolated from the biosphere.

23. Emerson, R. R. 1974. Preliminary Investigations of the Effects of Resuspended Sediment on Two Species of Benthic Polychaetes from Los Angeles Harbor. In: Marine Studies of San Pedro Bay, California. Part III, Thermal Tolerance and Sediment Toxicity Studies, D. F. Soule and M. Oguri, eds. USC-SG-1-74, University of Southern California, Office of Sea Grant Programs, Allen Hancock Foundation, Harbor Environmental Projects. pp. 97-110.

Laboratory bioassays were conducted with two marine polychaetes using elutriates from sediments collected in Los Angeles Harbor. Ninety-six hour tests revealed no mortality of Ophryotrocha nr. labronica; however, mortality was observed during similar tests with Capitella capitata. Sediments collected from various locations in the harbor yielded a range of contaminant levels. An apparent correlation was observed between mortality rates and both organic and inorganic contaminant levels in sediment. The author suggested that further testing was necessary.

24. Emerson, R. R. 1976. Bioassay and Heavy Metal Uptake Investigations of Resuspended Sediment on Two Species of Polychaetous Annelids. In: Marine Studies of San Pedro Bay, California. Part 11, Potential Effects on the Biota of Outer Los Angeles Harbor, Toxicity, Bioassay and Recolonization Studies, D. F. Soule and M. Oguri, eds. University of Southern California, Office of Sea Grant Programs, Allen Hancock Foundation, Harbor Environmental Projects. pp. 69-90.

"Two species of polychaetous annelids (Capitella capitata and Ophryotrocha sp.) were used in a series of bioassays to determine the toxicity of resuspended sediments from fourteen stations in Los Angeles Harbor. Significant mortality did not occur in either short-term (96-hour) or long-term (28-day) bioassays using Ophryotrocha sp. Numbers of offspring were significantly reduced in all sediments except the outermost harbor station (LNG-1), indicating sublethal effects. Development success of Capitella capitata larvae ranged from 40% to 95%. The more grossly contaminated sediments yielded lower numbers of successfully developing larvae but higher growth rates in the surviving larvae. Contamination levels of the sediments correlated more closely with sediment particle size than with distance from the outside harbor.

Heavy metal concentrations in the tissues of Capitella capitata did not correspond with sediment contamination levels. Resuspended sediment may result in "scavenging" which lowers the concentration of some heavy metals in the seawater." (author abstract)

25. Engler, R. M. 1980. Prediction of Pollution Through Geochemical and Biological Procedures: Development of Regulation Guidelines and Criteria for the Discharge of Dredged and Fill Material. In: Contaminants and Sediments, Vol. 1, R. A. Baker, ed. Ann Arbor Sciences Publishers, Inc., Ann Arbor, Michigan. pp. 143-169.

"Guidelines and criteria have been published (13, 14) for the ecological evaluations of the discharge of dredged and fill material into inland waters and the transportation of dredged material for dumping into ocean waters. A history of regulatory criteria development reveals that tests for describing the pollution-producing characteristics of dredged sediments were in use in the late 1960s and were similar to those used to evaluate the bulk characteristics of municipal and industrial wastes. This approach proved ineffective. Recent evaluative procedures use leaching tests for specific groups of contaminants; toxicity and bioaccumulation tests with various aquatic organisms; and general ecological evaluations of the proposed disposal sites. Implementation

manuals have subsequently been published and are in use. Field evaluation and verification have shown these manuals to be effective environmental management tools." (author summary)

26. Feng, S. Y. 1977. Thames River Hydrography, Phytoplankton, and Trace Metal Concentrations in Water, Sediment, and Shellfish. Section B in: Physical, Chemical, and Biological Effects of Dredging in the Thames River (Connecticut) and Spoil Disposal at the New London (Connecticut) Dumping Ground, Rep. No. 2 (Final Report). Interagency Scientific Advisory Subcommittee on Ocean Dredging and Spoiling, Division of Environmental Assessment, April 1977. 346 pp.

    "...Field surveys of the Thames River hydrography, phytoplankton, and trace metal concentrations in water, sediment, and shellfish suggested that effects of dredging on primary production were spatially and temporally limited. The highest concentrations of nickel, lead, cadmium and mercury in water samples were observed before or during dredging, while copper was highest after dredging but were generally higher upriver. Sediment levels of these five metals, plus zinc and organic carbon, increased in an upriver direction. Dredging related changes in trace metal body burdens (were observed) in shellfish but were difficult to separate from normal seasonal variations. No gross pathology was detected in the shellfish..." (author abstract)

27. Fujiki, M., R. Hirota, and S. Yamaguchi. 1977. The Mechanism of Methylmercury Accumulation in Fish. In: Management of Bottom Sediments Containing Toxic Substance, S. A. Peterson and K. K. Randolph, eds. EPA 600/3-77-083, U.S. Environmental Protection Agency, Office of Research and Development, Corvallis, Oregon. pp. 89-95.

    Red sea bream (Chrysophrys major) were held in laboratory aquaria containing Minamata Bay sediments (0.015 mg Hg/kg dry sediment) for 10 days. Concentrations of Hg in bream exposed to contaminated sediment were not different than bream held in control tanks.

28. Fulk, R., D. Gruber, and R. Wullschleger. 1975. Laboratory Study of the Release of Pesticide and PCB Materials to the Water Column During Dredging and Disposal Operations. Contract Rep. D-75-6, U.S. Army Engineers Waterways Experiment Station, Vicksburg, Mississippi, December 1975. 112 pp.

    Sediments, water column water, and interfacial water samples were collected from five sites (2 salt water, 3 freshwater of which two were in Lake Michigan) and analyzed for organic contaminants. Laboratory tests were conducted to estimate the release of organics to the water column upon resuspension of sediments and to determine settling times for desorbed contaminants. PCBs, DDT, and dieldrin were the most prevalent contaminants found in environmental samples. No correlation was found between PCB concentration and total organic carbon, oil and grease, or silt and clay in sediments or interstitial water. No measurable desorption of contaminants was observed at sediment to water ratios of 1:10 or lower, but desorption did occur at 1:5 ratios. PCBs remaining in

solution after various settling times were related to suspended oil and grease and suspended solids. The highest concentration of PCBs measured in settling tests was 0.03 µg/l.

29. Gannon, J. E., and A. M. Beeton. 1969. Studies on the Effects of Dredged Materials from Selected Great Lakes Harbors on Plankton and Benthos. Spec. Rep. No. 8, Center for Great Lakes Studies, University of Wisconsin, Milwaukee. 82 pp.

Laboratory bioassays were conducted with sediments collected from Buffalo, Calumet, Cleveland, Green Bay, Indiana, Rouge River, and Toledo harbors. The bioassays measured sediment selectivity by zooplankton, sediment toxicity to benthos, and effects of sediment on growth of phytoplankton based on carbon-14 uptake. The majority of tests were run under static conditions, some involved multiple additions of sediment, and most lasted one week or less. No correlations were evident between any biological parameter and physical measurement of sediment consisting of COD, NH_4, organic N, PO_4, and volatile solids.

30. Gannon, J. E., and A. M. Beeton. 1971. Procedures for Determining the Effects of Dredged Sediments on Biota-Benthos Viability and Sediment Selectivity Tests. J. Water Pollut. Control Fed., 43(3):392-398.

Laboratory tests were conducted with Pontoporeia affinis and sediments collected from nine Great Lakes harbors to determine selectivity (sediment preference) and viability (survival after 24- or 48-h exposure to sediments). Washed aquarium sand, Fullers Earth, open lake sediments from Lake Michigan, and sediment from one of the harbors (relatively unpolluted) were used as control sediments. Although no chemical analyses were performed on either sediments or overlying water, Pontoporeia avoided sediments from harbors thought to be highly polluted. In addition, those sediments considered as polluted caused higher mortality of Pontoporeia than control sediments.

31. Gillespie, D. C., and D. P. Scott. 1971. Mobilization of Mercuric Sulfide from Sediment into Fish under Aerobic Conditions. J. Fish Res. Board Can., 28:1807-1808.

Guppies (Poecilia reticulata) were held in laboratory aquaria containing sediments spiked to 50 µg/g (dry wt.) $HgCl_2$, HgS, or controls (0.24 µg/g Hg). After 55 days, Hg concentrations were found to be 2.7 µg/g in fish exposed to Hg Cl_2, 1.6 µg/g for fish in the HgS treatment, and 1.1 µg/g in control fish.

32. Halter, M. T., and H. E. Johnson. 1977. A Model System to Study the Desorption and Biological Availability of PCB in Hydrosoils. In: Aquatic Toxicology and Hazard Evaluation, ASTM STP 634, F. L. Mayer and J. L. Hamelink, eds. American Society for Testing and Materials, Philadelphia, Pennsylvania. pp. 178-195.

Laboratory studies were conducted with fathead minnows exposed to natural sediments spiked with PCBs (10 µg/g to 500 µg/g). Bioaccumulation tests

were run under flow-through conditions; and some tests used a screen to separate the fish from the sediment, while other tests used no screen, thereby allowing contact between fish and sediment. The maximum duration of the bioaccumulation tests was 32 days. Fish allowed contact with contaminated sediment accumulated levels of PCBs (2.7 μg/g - 99.6 μg/g) six times those of the fish that were screened from contact with the sediments (0.6 μg/g - 18.5 μg/g). Desorption of PCBs from spiked sediments was also measured under static and flow-through conditions and equilibrium concentrations were related to PCB concentrations in the sediment.

33. Haven, D. S. and R. Morales-Alamo. 1978. Uptake of Kepone from Suspended Sediments by Oysters, Rangia and Macoma. In: Kepone in the Marine Environment: Publications and Prepublications, Appendix C to the EPA Kepone Mitigation Feasibility Project. EPA-440/5-78-004C, U.S. Environmental Protection Agency. pp. 237-288.

Laboratory experiments were conducted exposing oysters (Crassostrea virginica) and clams (Rangia cuneata) and Macoma balthica) to kepone-contaminated sediment from the James River (Virginia). These bivalves concentrated kepone 1000-3000 times the water concentration when sediment was resuspended. Strong correlations were observed in tests conducted over a four-week period between concentrations of kepone in oysters and in sediments and the results indicated a leveling of concentrations in animals after one week of exposure. When Crassostrea and Rangia were buried in sediment and low water flow kept sediments from being resuspended, little kepone accumulation occurred.

34. Heit, M., C. S. Klusek, and K. M. Miller. 1980. Trace Element, Radionuclide, and Polynuclear Aromatic Hydrocarbon Concentrations in Unionidae Mussels from Northern Lake George. Environ. Sci. Technol., 14(4):465-468.

Samples of freshwater mussels and associated sediment were collected from Lake George (New York) and analyzed for levels of trace elements, radionuclides, and polynuclear aromatic hydrocarbons (PAHs). Concentration ratios (CR--muscle tissue concentration/sediment concentration) for the three species of mussels collected were about 30 for Cd, 10 for Hg, 9 for Se, 7 for Zn, and 2 for Cu. Cr, Ni, and Pb had CRs of about 1, while As and Sn appeared not to be accumulated. Radionuclides associated with fallout from weapons tests were accumulated in Elliptio complanatus. PAH concentrations in mussels were found to vary greatly between individuals.

35. Herdendorf, C. E., and C. L. Copper. 1976. Investigations of Larval Fish Populations in Maumee River Estuary and Bay and Assessment of the Impact of Commercial Sand and Gravel Dredging on These Populations. Center for Lake Erie Area Research, Ohio State University, Columbus. 86 pp.

Field studies were conducted in conjunction with dredging activity in the Maumee River estuary. Surface and bottom tows with plankton nets

collected fish larvae at thirteen stations. Authors concluded that dredging activities reduce fish larvae densities in the vicinities of the dredges. Larvae caught in the wash water used to process the dredged material are destroyed. Larval movements are largely controlled by water currents.

36. Hirota, R., M. Fujiki, Y. Ikegaki, and S. Tajima. 1978. Accumulation of Mercury by Fish from Contaminated Sediments. In: Proceedings of the Fourth U.S.-Japan Experts' Meeting, Tokyo, Japan. pp. 225-240.

Field studies were conducted using fish caged in Minimata Bay. Fish were reared for up to 6 months with samples collected every 10 days. Correlations were calculated between mercury and body length of fish. The authors concluded that all fish species did not accumulate mercury at the same rate or to the same extent and therefore selected species of different ages should be used if a mercury monitoring program was implemented in Minamata Bay.

37. Hirsch, N. D., L. H. DiSalvo, and R. K. Peddicord. 1978. Effects of Dredging and Disposal on Aquatic Organisms. Tech. Rep. DS-78-5, U.S. Army Corps of Engineers, Vicksburg, Mississippi. 41 pp.

A synthesis of six DMRP reports dealing with dredging effects on aquatic organisms. Three of these reports dealt with laboratory studies examining contaminant effects. This summary report concluded that: (1) uptake of sediment-associated heavy metals by organisms was rare; (2) bulk analysis of sediments for metals did not reflect their potential environmental impact; and (3) oil and grease residues were tightly bound to sediment, making them mostly unavailable for uptake.

38. Hoke, R. A., and B. L. Prater. 1980. Relationship of Percent Mortality of Four Species of Aquatic Biota from 96-hour Sediment Bioassays of Five Lake Michigan Harbors and Elutriate Chemistry of the Sediments. Bull. Environ. Contam. Toxicol., 25:394-399.

Laboratory bioassays were conducted using sediments collected from five Lake Michigan harbors: Indiana Harbor (Indiana), Grand Haven (Michigan), New Buffalo (Michigan), Green Bay (Wisconsin), and Marinette-Menominee (Wisconsin-Michigan). Pimephales promelas, Hexagenia limbata, Lirceus fontinalis, and Daphnia magna were held in a recirculating system in the presence of the sediment. Correlations were tested between 96-hour mortality (percent) and elutriate chemical data (NH_3, COD, TP, TKN, NO_3^+, NO_2, Cl^-, $SO_4^=$, As, Cd, Cu, Fe, Pb, Mn, Ni, and Zn). Sixty bivariate correlation analyses revealed only 4 significant correlations: mortality of P. promelas and chloride concentration, mortality of H. limbata, and concentrations of chloride, ammonia and nickel. The authors questioned the utility of elutriate testing in evaluating ecological effects of dredged material disposal.

39. International Working Group on the Abatement and Control of Pollution from Dredging Activities Report. May 1975. International Working Group on the Abatement and Control of Pollution from Dredging Activities. 227 pp.

The Working Group reviewed existing dredging practices and regulations and discussed potential environmental effects. The report contains a literature review on various aspects of dredging and concludes that present techniques of sediment analysis do not provide adequate information on bioavailability of toxic substances.

40. Jernelov, A. 1970. Release of Methylmercury from Sediments with Layers Containing Inorganic Mercury at Different Depths. Limnol. Oceanogr., 15(6):958-960.

Laboratory experiments examined Hg uptake by Lebistes reticulatus held over columns of sediment in which layers were spiked with 100 µg/g $HgCl_2$ at various depths. Along with the fish, either Tubificidae, Anodonta, or no macrofauna were added to test tanks. With no macrofauna, uptake by fish only occurred from the spiked surface sediments when mercury was available at the surface. In the presence of Tubificidae, Hg was available for accumulation down to a depth of 2 cm, while in the presence of Anodonta, Hg was available down to a depth of 9 cm.

41. Kneip, T. J., and R. E. Hazen. 1979. Deposit and Mobility of Cadmium in a Marsh-Cove Ecosystem and the Relation to Cadmium Concentration in Biota. Environ. Health Perspect., 28:67-73.

"The study reported here presents the results of an investigation of a marsh-cove ecosystem heavily contaminated by cadmium. The most contaminated aquatic sediments were dredged in 1972-73, but the resuspension of the sediments and recycle of water from the dredge spoil resulted in reestablishment of a large, contaminated sediment bed with concentrations very similar to those observed before dredging.

The stability of the sediment concentrations and shallow depth of the cadmium in the sediments indicate that the deposit is relatively stable in agreement with the expectations based on the water chemistry of the system.

Uptake does occur in both marsh and aquatic plants and all species of animals tested. Significantly elevated concentrations are observed compared to noncontaminated areas; however, edible portions of most fish do not appear to present a hazard. Crabs appear to present the most likely source of a hazard to humans. This potential hazard is still under investigation.

The dredging removed about 5.5 MT of cadmium, about one-fourth of that originally estimated to be present, but twice that amount is found to be in the cove sediments 3 to 4 years after dredging. No appreciable improvement in the ecosystem has been made, and more careful

consideration should be given to the need for decontamination and the method of removal of contaminated aquatic sediments in any future case." (author abstract)

42. Kudo, A. 1976. Mercury Transfer from Bed Sediments to Freshwater Fish (Guppies). J. Environ. Qual., 5(4):427-430.

Static bioassays were conducted in the laboratory exposing guppies (Lebistes reticulata) to sediment containing 523 ng/g (dry weight) naturally deposited Hg and additional 500 ng/g of spiked ^{203}Hg. Four groups of guppies were consecutively exposed to the same sediment for periods of 23-51 days. Continuous accumulation was observed in all groups with high individual variation (600%). No correlation between uptake and size or sex of fish was observed. In depuration studies, half-lives ranged between 38 and 75 days.

43. Kudo, A., and D. C. Mortimer. 1979. Pathways for Mercury Uptake by Fish from Bed Sediments. Environ. Pollut., 19(3):239-245.

Guppies (Lebistes reticulata) were exposed in the laboratory to sediments collected from the Ottawa River (Canada) to determine the route of mercury uptake by the fish. Mercury (as mercuric chloride) was added to the already contaminated (0.523 µg/g Hg) river sediment to attain a Hg concentration of 1.023 µg/g based on dry weight. Radioactive mercury (^{203}Hg, 47 days half life) was introduced into the sediment as a tracer and analysis performed by measuring radioactivity of live fish. Exposures were conducted in a two-chambered tank connected by two glass tubes screened at both ends. This allowed water to flow between the chambers, but fish were restricted to one side or the other. In this study, sediment was introduced into one chamber and fish into one side or the other. Analysis revealed that fish in contact with the sediments accumulated 9 times more mercury than fish exposed to water alone.

44. Lang, C., and B. Lang-Dobler. 1979. The Chemical Environment of Tubificid and Lumbriculid Worms According to the Pollution Level of the Sediment. Hydrobiologia, 65(3):273-282.

The authors collected 170 sediment samples from Lake Geneva (Switzerland) and analyzed the samples for the presence of worms and ten chemical variables (organic carbon, total P, Cd, Zn, Sn, Pb, Hg, Cu, Cr, and Mn). Fourteen tubificid and 2 lumbriculid worm species were detected in the sediment samples that were also classified by physical variables, percentage of sand, silt, and clay, and depth. Factorial correspondence analysis described relationships between worm species and chemical and physical variables. Six worm species groups were identified, each characterized by different chemical variables indicating varying levels of pollution.

45. Laskowski-Hoke, R. A., and B. L. Prater. 1981. Relationship of Mortality of Aquatic Biota from 96-hour Sediment Bioassays and the Change in Chemical Composition of the Test Water. Bull. Environ. Contam. Toxicol., 26:323-327.

Laboratory bioassays were conducted exposing Pimephales promelas, Hexagenia limbata, Lirceus fontinalis, and Daphnia magna to sediments collected from five Lake Michigan harbors. Mortality was measured in these flow-through tests and correlated with a value described as the "difference chemistry value." The value was the pretest water concentration subtracted from the posttest water concentration of a number of water quality parameters. Mortality of P. promelas was significantly correlated with difference chemical values for $NO_3 + NO_2$, NH_3, TKN, and total P. H.limbata mortality was correlated with suspended solids, NH_3, Cd, Cr, CN^-, Hg, and Zn. D. magna mortality was correlated with CN^- and Zn, while L. fontinalis was correlated with NH_3.

46. Laube, V., S. Ramamoorthy, and D. J. Kushner. 1979. Mobilization and Accumulation of Sediment Bound Heavy Metals by Algae. Bull. Environ. Contam. Toxicol., 21(6):763-770.

A laboratory experiment was conducted in which two species of algae, Anabaena and Ankistrodesmus braunii were exposed to Ottawa River (Canada) sediment and bioaccumulation of Cd and Cu was measured. Sediment, to which either Cd or Cu nitrate salts were added, and algae were placed in separate dialysis bags. The bags were suspended in river water and rotated for 72 hours. Anabaena accumulated 20 ppm Cd and A. braunii accumulated 9 ppm Cd from sediment containing 100 ppm Cd. From sediment containing a natural level of 50 ppm Cu (and an added 1 ppm), Anabaena accumulated 20 ppm and A. braunii 7 ppm.

47. Lee, C. R., R. E. Hoeppel, P. G. Hunt, and C. A. Carlson. 1976. Feasibility of the Functional Use of Vegetation to Filter, Dewater, and Remove Contaminants from Dredged Material. Tech. Rep. D-76-4, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, June 1976. 107 pp.

This report evaluates the feasibility of using vegetation in dredge spoil containment areas to improve discharge water quality. The authors concluded that selected vegetation could remove significant amounts of nitrogen and phosphorus from the discharge water and improve the quality of the water, but the use of vegetation to remove heavy metals has limited feasibility. Included in the report is a literature search with numerous references on the uptake of metals from contaminated sediments by plants and the potential for these metals then entering the food chain.

48. Lee, G. F., J. M. Lopez, and G. M. Mariani. 1976. Leaching and Bioassay Studies on the Significance of Heavy Metals in Dredged Sediments. Center for Environmental Studies, University of Texas. 68 pp.

A series of laboratory toxicity tests were conducted using sediments from: Mobile, Alabama; Ashtabula, Ohio; San Francisco and Los Angeles, California; Bridgeport, Connecticut; and Trinity River, Houston Ship Channel, Galveston, Texas City, Corpus Christi, Port Aransas, and Port Lavaca, Texas. These studies were short term ($\leq$ 96-h static toxicity tests) on dilutions of elutriate water. The authors conclude that "the

toxicity of the sediment elutriate mixtures was insufficient to be adverse to aquatic organisms in a typical open water disposal site water column".

49. Lee, G. F., M. D. Piwoni, J. M. Lopez, G. M. Mariani, J. S. Richardson, D. H. Homer, and F. Saleh. 1975. Research Study for the Development of Dredged Material Disposal Criteria. Contract Rep. D-75-4, U.S. Army Waterways Experiment Station, Vicksburg, Mississippi. 381 pp.

This report provides information on elutriate tests run on sediments collected across the country. Toxicity tests were run on sediments from two locations and both were basic static exposures. The dissolved oxygen content of the elutriate influenced the release of chemical contaminants from the dredged sediments. The authors recommended a modified Elutriate Test which allowed for aeration during the preliminary mixing period. They also recommended that the sediment volume be reduced from 20 percent to 5 percent.

50. Lee, G. F., and R. H. Plumb. 1974. Literature Review on Research Study for the Development of Dredged Material Disposal Criteria. Contract Rep. D-74-1 U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi. 145 pp.

This literature review contains 163 references on dredging, disposal, and their effects. Several references deal with the effects of toxic substances on biota and none deal with bioaccumulation.

51. Lindberg, S. E., and R. C. Harris. 1977. Release of Mercury and Organics from Resuspended Near Shore Sediments. J. Water. Pollut. Control Fed., 49(12):2479-2487.

Sediments were collected from Mobile Bay (Alabama) and the Shark River (Florida), and placed in 14-l bottles with their associated overlaying water. Sediments were resuspended mechanically for 6 hours and water samples taken and analyzed. In all sediment-water samples tested, large increases in dissolved Hg were observed shortly after sediment resuspension. No consistent correlation was found between this increase and changes in pH, redox potential, total dissolved sulfide, or dissolved organic carbon.

52. Luoma, S. N., and E. A. Jenne. 1975. Factors Affecting the Availability of Sediment-Bound Cadmium to the Estuarine, Deposit-Feeding Clam. In: Radioecology and Energy Resources, C. E. Cushing, Jr., ed. Dowden, Hutchinson, and Ross, Inc., Stroudsburg, Pennsylvania. pp. 283-290.

Laboratory studies were conducted under static water conditions using estuarine clams (Macoma balthica). The clams were exposed to ^{109}Cd-spiked sediment for 14 to 42 days in a number of experiments. Sediments were chemically extracted to compare results with uptake in clams. These studies were conducted to estimate the relative contribution of ^{109}Cd to the organism from ingestion of sediment or direct uptake from the water. Some uptake of Cd by clams through

ingestion of spiked natural sediment was observed, but the concentrations of ^{109}Cd in the clam were never greater than 10 percent of the concentrations of ^{109}Cd in the sediment. No correlations were observed between chemical entraction of sediment and the bioavailability of ^{109}Cd.

53. Lyes, M. C. 1979. Bioavailability of a Hydrocarbon from Water and Sediment to the Marine Worm Arenicola marina. Mar. Biol., 55:121-127.

Worms were collected from Booterstown Strand (Eire) and exposed in the laboratory to sediments spiked with ^{14}C-1-naphthalene. Sediments were rinsed with water prior to introduction of organisms. After five hours, concentration factors (cf) ranged from 0.1 to 4.1 for various tissues analyzed separately. Stomach wall tissue had the highest cf, while body wall cf was approximately 0.5.

54. Lynch, T. R., and H. E. Johnson. 1982. The Availability of a Hexachlorobiphenyl Isomer to Benthic Amphipods from Experimentally-Contaminated Sediments. In: Aquatic Toxicology and Hazard Assessment: Proceedings of the Fifth Annual Symposium on Aquatic Toxicology, J. G. Pearson, R. B. Foster, and W. E. Bishop, eds. American Society for Testing and Materials. Philadelphia, PA. pp. 273-287.

"The present study was designed to determine the availability of radiolabeled 2,4,5,2',4',5', -hexachlorobiphenyl (HCBP) to benthic amphipods from experimentally-contaminated sediments. Amphipods accumulated HCBP primarily by direct uptake from water as a function of exposure time. However, organisms that were directly exposed to the sediments had consistently higher (2.3 to 10.8X) HCBP concentrations than did organisms exposed only to the sediment-desorbed residues in the water. Experimental results demonstrated that substrate organic matter content, particle size, and sediment mineralogy affected the concentrations of HCBP in the water and, in turn, in the organisms. Removal of sediment organic matter enhanced HCBP accumulation by both substrate-exposed and water-exposed organisms. Amphipods accumulated the least HCBP when exposed to silt-clay particle size fractions which contained organic matter." (author abstract)

55. Marking, L. L., V. K. Dawson, J. L. Allen, T. D. Bills, and J. J. Rach. 1981. Biological Activity and Chemical Characteristics of Dredged Material from Ten Sites on the Upper Mississippi River. Summary Report, National Fishery Research Laboratory, U.S. Fish and Wildlife Service, LaCrosse, Wisconsin. 145 pp.

Laboratory toxicity tests were conducted under static conditions for 96 hours using a variety of freshwater invertebrates and fish. Sediments were analyzed for nutrients, metals, PCBs, and pesticides by bulk, suspended particulate, and elutriate procedures. Exposure vessels were aerated to maintain the sediment in suspension. Over half of the water volume in each vessel was replaced daily. Sediments from two locations were toxic and the particulate phase exposures were more toxic than the solid phase exposures.

56. McCain, B. B., H. O. Hodgins, W. D. Gronlund, J. W. Hawkes, D. W. Brown, M. S. Myers, and J. H. Vandermeulen. 1978. Bioavailability of Crude Oil from Experimentally Oiled Sediments to English Sole (Paraphrys vetulus), and Pathological Consequences. J. Fish. Res. Board Can., 35:657-664.

"English sole (Paraphrys vetulus) were exposed to experimentally oiled (Alaskan North Slope crude oil) sediments over a 4-mo period to assess the bioavailability and tissue hydrocarbon distribution kinetics in flatfish. Data were also obtained on hydrocarbon related physiological changes and tissue pathology. Crude oil was mixed with aromatic hydrocarbon-free sediments to a concentration of 700 μg/g dry weight at the beginning of the experiment. During the 1st mo of the experiment this concentration decreased to 400 μg/g dry weight, and remained relatively stable during the remainder of the 4-mo period. Compositional changes were observed in the alkane and aromatic fractions, with a differential decrease in the substituted naphthalenes. Flatfish maintained in such oiled sediments readily took up alkane and aromatic petroleum hydrocarbons from these sediments, and accumulated these in skin, muscle, and liver; 1-and 2-methylnaphthalene and 1,2,3,4-tetramethylbenzene were accumulated to great extent than other aromatics. Tissue hydrocarbons decreased with time, and after 27-d continuous exposure to oiled sediments only the liver contained detectable levels of hydrocarbons. After 2 months, <2% of the initial aromatic hydrocarbon load could be detected, and only in the liver in flatfish that were continuously maintained on oiled sediments. Depuration of tissue aromatics differed for various aromatics, 1,2,3,4-tetramethylbenzene and 2-methylnaphthalene being most persistent. Depuration is thought to be due to induction of the aryl hydrocarbon hydroxylase system during initial exposure to oiled sediments. Concomitant with the high tissue hydrocarbon period were found enhanced weight loss and severe hepatocellular lipid vacuolization (HLV). Although the observations on growth changes and liver pathology are preliminary, the data indicate the need for further detailed study of fish growth abnormalities and pathology in the presence of petroleum hydrocarbons." (author abstract)

57. McConaugha, J. R. 1976. Toxicity and Heavy Metals Uptake in Three Species of Crustacea from Los Angeles Harbor Sediments. In: Marine Studies of San Pedro Bay, California. Part 11, Potential Effects on the Biota of Outer Los Angeles Harbor, Toxicity, Bioassay and Recolonization Studies, D. F. Soule and M. Oguri, eds. University of Southern California, Office of Sea Grant Programs, Allen Hancock Foundation, Harbor Environmental Projects. pp. 49-68.

"Two species of crustaceans, Acartia tonsa and Tisbe sp., were subjected to the filtrate fraction (<0.45) of resuspended sediments from 12 stations in the Los Angeles Harbor. The 96 hour bioassays for A. Tonsa produced significant reductions in the survival rates of test groups at stations LNG-6, LNG-7, 16, 17, 18, 24 and 27. In the Tisbe bioassays, only station LNG-7 had significantly lower survival in the test group than in controls, while test group survival at stations LNG-4, -25 and -27 were significantly higher than control survival. This data suggests

that dredging operations could have an adverse effect on the A. Tonsa population and consequently an effect on the plankton composition and food chain in the Los Angeles Harbor. However, the stations with poorest quality are in the area to be filled.

Additional experiments were conducted to determine if the lined shore crab, Pachygropsus crassipes, was capable of accumulating heavy metals from resuspended sediments. Following a 7-day exposure to the sediment elutriate, the gill tissue was examined for 9 heavy metals. Because of extreme variations in the data, no discernible trends were observed." (author abstract)

58. McLeese, D. W., and C. D. Metcalfe. 1980. Toxicities of Eight Organochlorine Compounds in Sediment and Seawater to Crangon septemspinosa. Bull. Environ. Contam. Toxicol., 25:921-928.

Beakers of sandy sediment (97% sand, 0.5 to 2.0 mm) were fortified in a laboratory experiment with various concentrations of one of the following organochlorines: endrin, endosulfan, DDT, dieldrin, chlordane, Aroclor 1242, Aroclor 1254, and hexachlorobenzene. Static bioassays were conducted with the shrimp C. septemspinosa to determine LC_{50} values for the contaminants in water and in sediment. LC_{50} values were 10-80 times higher for contaminants in sediment when compared to values for contaminants in water.

59. McLeese, D. W., D. C. Metcalfe, and D. S. Pezzack. 1980. Uptake of PCB's from Sediment by Nereis virens and Crangon septemspinosa. Arch. Environ. Contam. Toxicol., 9:507-518.

Two polychaete worms (Nereis virens and Glycera dibranchiota) and the shrimp Crangon septemspinosa were exposed to PCB-fortified sediments in the laboratory. Sediment PCB levels ranged from 0.04 to 0.58 mg/kg (dry). Exposure time, organism size, and sediment type were other variables tested. Authors observed that uptake by organisms was directly related to sediment concentration and inversely related to organism size. Equilibrium concentrations were not attained after 32 days of exposure and concentration factors seemed greater from sandy sediment than from muddy sediment.

60. Moore, J. W. 1981. Epipelic Algal Communities in a Eutrophic Northern Lake Contaminated with Nine Wastes. Water Res., 15(1):97:105.

"The effects of contaminated bottom sediments on the species composition, growth cycles and diversity of epipelic algal communities were determined between April and November 1978 in a shallow, eutrophic lake (Thompson Lake) situated in the Canadian subarctic. The sediments had become contaminated by gold mining wastes, deposited in the lake between 1941 and 1949. Although the concentrations of total mercury, copper, lead and zinc were high near the mine, averaging 440 g kg^{-1}, and 95, 30 and 115 mg kg^{-1}, respectively, they decreased rapidly beyond this distance and were near background levels 2.1-3.0 km from the mine. The algal communities in the zone of heaviest contamination consisted of 63

species, the most common of which were Anomoconeis vitrea, Pinnularia brebissonii and Cymbella species. There were more taxa (111-132) at stations situated 1.1-3.0 km from the mine and the main species included several forms of Achnanthes, Fragilaria, and Navicula. Although epipelic densities in the zone of heaviest contamination were only about 50% of those recorded at the other stations, the seasonal growth patterns of the flora were generally similar thoughout the lake. Based on these data, it is concluded that: (1) Mine wastes may have a long-term impact on epipelic algae in northern environments; (2) The effects of heavy metal pollution on the epipelon in subarctic lakes are similar to those in temperate zone systems; and (3) No species or group of species could be designated as indicators of heavy metal contamination." (author abstract)

61. Morton, J. W. 1977. Ecological Effect of Dredging and Dredge Spoil Disposal: A Literature Review. Tech. Pap. 94, U.S. Fish and Wildlife Service. 33 pp.

A literature review on the effects of dredging and disposal in estuarine environments. Few references are presented dealing with bioaccumulation or effects of contaminants associated with resuspended sediments.

62. Nathans, T. J., and T. J. Bechtel. 1977. Availability of Sediments-Absorbed Selected Pesticides to Benthos with Particular Emphasis on Deposit-Feeding in Fauna. Tech. Rep. D-77-34, U.S. Army Engineers Waterways Experiment Station, Vicksburg, Mississippi. 83 pp.

Laboratory studies were conducted in a mobile lab using natural sea water, either in a flow-through or recycling exposure system. Tests were run with artificial sediments spiked with radiolabled DDT using 3 species of invertebrates. Studies were run for a maximum of 25 days. A number of problems with the study were identified by the authors and the sponsoring agency. The organisms were not totally depurated before analysis, no measurements of DDT were made in the organisms before exposure, and the sediments used were composed sand, clay, and aged cereal. Accumulation of DDT was measured in all 3 species of invertebrates.

63. Neff, J. W., R. S. Foster, and J. F. Slowey. 1978. Availability of Sediment-Adsorbed Heavy Metals to Benthos with Particular Emphasis on Deposit-Feeding in Fauna. Tech. Rep. D-78-42, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi. 311 pp.

Laboratory studies were conducted to evaluate the availability to benthic invertebrates of metals associated with sediments. A number of invertebrates were exposed to natural sediments for 6 weeks, under static conditions. Statistically significant accumulation of metals was demonstrated only 36 times out of 136 metal-species-sediment test combinations. No correlations were measured between accumulation in organisms and bulk analyses or selective extraction procedures applied to the sediments.

64. Nimmo, D. R., P. D. Wilson, R. R. Blackman, and A. J. Wilson, Jr. 1971. Polychlorinated Biphenyl Absorbed from Sediments by Fiddler Crabs and Pink Shrimp. Nature, 231:50-52.

Shrimp (Penaeus durarum) and crabs (Uca pugilator) were held in aquaria containing either contaminated sediments collected from Escambia Bay (Florida), or control sediment (beach sand). Aroclor 1254 was found to be accumulated by both species after 30 days of exposure. PCB concentrations in the organisms correlated with levels of PCBs in sediment.

65. Peddicord, R. K., and V. A. McFarland. 1978. Effects of Suspended Dredged Material on Aquatic Animals. Tech. Rep. D-78-29, U.S. Army Engineers Waterways Experiment Station, Vicksburg, Mississippi. 115 pp.

Laboratory experiments were conducted to evaluate the impact of suspensions of sediments on fish and invertebrates. Studies were conducted for 21 days and both survival and accumulation of contaminants were measured when harbor sediments were used. The system used was an elaborate continuous-flow system. Fish survived suspensions of grams of sediment per liter while invertebrates survived tens of grams per liter. Fingerling striped bass showed the greatest sensitivity to sediment suspension. Accumulation of contaminants was measured in only about one fourth of the exposures where uptake could possibly have been measured.

66. Peddicord, R., H. Tatem, A. Gibson, and S. Pedron. 1980. Biological Assessment of Upper Mississippi River Sediments. Misc. Pap. EL-80-5, U.S. Army Engineers Waterways Experiment Station, Vicksburg, Mississippi. 82 pp.

Laboratory studies were conducted to examine acute toxicity and the potential for PCBs and metals to bioaccumulate in fish and invertebrates when exposed to sediment. These tests were run for 4 to 14 days under static water conditions (some experiments were done with water replacement). The sediments used were altered by removal of coarse grained materials (>200 mesh). Acute toxicity tests were conducted using mayfly larvae, freshwater amphipods, and Daphnia. Bioaccumulation tests were run with fish and clams. Fish exposed to sediments accumulated PCBs, Cd, and Zn while clams only accumulated PCBs. Toxicity data were quite variable and no correlations were measured between toxicity data and analyses of chemicals in the sediment or bioaccumulation.

67. Pequegnat, W. E., R. R. Fay, and T. A. Wastler. 1980. Combined Field-Laboratory Method for Chronic Impact Detection in Marine Organisms and Its Application to Dredged Material Disposal. In: Estuarine and Wetland Processes, With Emphasis on Modeling, P. Hamilton and K. B. MacDonald, eds. Plenum Press, New York. pp. 631-648.

Field exposures of organisms held in "Biotal Ocean Monitor" were conducted and enzyme activity was measured in the organisms after they were returned to the laboratory. ATPase, catalase, and cytochrome P-420 and P-450 were measured in exposed organisms. Tests were conducted on

incineration wastes, sewage and sludge disposal activities. Some changes in enzyme activity were measured in the studies conducted; however, these changes must now be related to the operations being studied to establish a true cause-effect relationship.

68. Petrocelli, S. R., and J. W. Anderson. 1976. Distribution and Translocation of Residues of Dieldrin--A Chlorinated Hydrocarbon Insecticide--Among Water, sediments, and Estuarine Organisms from San Antonio Bay. In: Shell Dredging and Its Influence on Gulf Coast Environments, A. H. Bouma, ed. Gulf Publishing Co., Houston, Texas. pp. 185-218.

Clams (Rangia cuneata) and oysters (Crassostrea virginica) were collected from Hynes Bay, Texas, and exposed to sediment which had been collected from the same area and later spiked with 86.56 µg/kg ^{14}C-dieldrin. After exposures of 6 to 96-hours in flow-through systems, clams accumulated up to 17 µg/kg and oysters accumulated 20 µg/kg dieldrin, which was 20 and 23% of the sediment level of dieldrin, respectively.

69. Plumb, R. H., Jr. 1976. A Bioassay Dilution Technique to Assess the Significance of Dredged Material Disposal. Misc. Pap. D-76-6, U.S. Army Engineers Waterways Experiment Station, Vicksburg, Mississippi. 16 pp.

A modification of a typical algal response test was conducted with dilution of nutrients throughout the exposure period to simulate the dilution that takes place during the disposal of dredged material in open water. The author concluded that the algae was not significantly affected when the dilution rate at the open-water site was considered.

70. Prater, B. L., and M. A. Anderson. 1977. A 96-hour Sediment Bioassay of Duluth and Superior Harbor Basins (Minnesota) Using Hexagenia limbata, Asellus communis, Daphnia magna, and Pimephales promelas as Test Organisms. Bull. Environ. Contam. and Toxicol., 18(2):159-169.

Laboratory bioassays were conducted using sediments collected from Duluth, Minnesota, and Superior, Wisconsin, harbors in Lake Superior. Hexagenia limbata, Asellus communis, Daphnia magna, and Pimephales promelas were held in a recirculating system in the presence of sediment. Mortality after 96-hour exposures ranged from 0 to 75%, depending on origin of sediment. D. magna were the most sensitive organisms, followed by H. limbata, A. communis, and P. promelas. Of the chemical parameters measured, no one parameter appeared responsible for observed mortality.

71. Prater, B. L., and M. A. Anderson. 1977. A 96-hr Bioassay of Otter Creek, Ohio. J. Water Pollut. Control Fed., 49(10):2099-2106.

A recycling bioassay apparatus was developed and tested for use in exposing aquatic organisms to sediments in the laboratory. After 96-hr exposure to sediments collected in Otter Creek, Ohio, mortality was measured in Hexagenia limbata, Asellus communis, and Daphnia magna. Sediment analysis revealed high concentrations of various metals at several sampling stations; organic contaminant concentrations were mostly

below detection limits. The apparatus consisted of a rectangular glass tank which housed the organism and sediment. Water recirculated through two, 4-liter glass jars by siphon and into the test tank via an air lift. Mortality ranged from 0 to 100% in all three organisms with D. magna being sensitive.

72. Prater, B. L., and R. A. Hoke. 1979. Statistical analyses of bulk sediment, elutriate, and bioassay sediment evaluation procedures. U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, Mississippi. Contract No. DACW39-79-M-3098. Final Report 206 p.

Recycling bioassays, bulk chemical analyses and elutriate analyses were conducted on sediments collected from five Lake Michigan harbors ranging from lightly to heavily polluted. Results of tests with three species of invertebrates and one fish species were subjected to bivariate and canonical correlations to examine which tests and parameters correlate with one another and to possibly reduce the number of chemical variables considered. The results indicated that mortality of the three invertebrate species in bioassay testing was more related to bulk sediment analyses than to elutriate chemistry. These conclusions were based mostly on heavy metals present in sediment as organic contaminants were not analyzed. Total volatile solids, oil and grease, TKN, and NH_3, were found to be related to test organism mortality. Results of these tests however, may have been affected by the fact that sediments were frozen prior to testing, which may have altered sediment chemistry.

73. Prouse, N. J., and D. C. Gordon, Jr. 1976. Interactions Between the Deposit Feeding Polychaete Arenicola marina and Oiled Sediment. In: Sources, Effects and Sinks of Hydrocarbons in the Aquatic Environment. American Institute of Biological Sciences. pp. 407-422.

Arenicola worms were tested in the laboratory in sediments artificially oiled with No. 2 fuel oil. Concentrations over 100 µg/g oil in sediment caused worms to leave their burrows, while 10 µg/g concentrations decreased the rate of cast production.

74. Qasim, S. R., A. T. Armstrong, J. Corn, and B. L. Jordan. 1980. Quality of Water and Bottom Sediments in the Trinity River. Water Res. Bull., 16(3):522-531.

Laboratory elutriate tests were conducted using sediments collected from the Trinity River (Texas). Acute toxicity tests (96-hr) were performed on Daphnia magna with 6 and 20% elutriates, with raw river water serving as a control. Results of these static tests revealed lowest survival by Daphnia in control water. Elutriation improved water quality by lowering the concentrations of nitrogen, phosphorus, carbon and heavy metals. The extent to which these substances were removed depended on both the saturation state and adsorptive capacity of the sediments.

75. Reimold, R. J., and C. J. Durant. 1974. Toxaphene Content of Estuarine Fauna and Flora Before, During and After Dredging Toxaphene-Contaminated Sediments. Pestic. Monit. J., 8(1):44-49.

A field study was conducted in which samples of sediment, cordgrass (Spartina alterniflora), oysters (Crassostrea virginica), and mummichog (Fundulus heteroclitus) were collected before, during, and after dredging. The authors found no increase in toxaphene concentrations in oysters throughout the period of dredging activity. Some increases were observed, however, in the cordgrass and mummichogs. Maximum concentrations measured in cordgrass leaves and mummichogs were 36.3 µg/g dry weight and 217.1 µg/g wet weight, respectively.

76. Renfro, W. C. 1973. Transfer of ^{65}Zn from Sediments by Marine Polychaete Worms. Mar. Biol., 21:305-316.

"Silty marine sediments spiked with ^{65}Zn lose only small fractions of their radioactivity when exposed to slowly flowing seawater for several weeks. However, polychaete worms (Nereis diversicolor), burrowing through the sediment, cause ^{65}Zn losses 3 to 7 times higher than in sediment without worms. Long-term experiments on the uptake and loss of ^{65}Zn by the polychaete Hermione hystrix indicate that 60 or more days exposure are required for this worm to approach steady state with ^{65}Zn in the sediment. Biological half-life estimates for ^{65}Zn accumulated from sediment by H. hystrix are extremely variable (52 to 197 days), depending on the loss-time interval chosen for the calculation. Following 5 days exposure to 16 cm^3 of radioactive sediment, N. diversicolor individuals contained an average of 0.2% of the total ^{65}Zn in the sediment. When these worms were transferred to non-radioactive sediment, estimates of biological half-life for ^{65}Zn averaged 14 to 17 days during the loss period Day 3 to Day 15. Based on these experimental results, it is estimated that a population of N. diversicolor could cause an annual loss of 3% or more of the ^{65}Zn in the upper 2 cm of the sediment of a hypothetical radioactive estuary." (author abstract)

77. Rose, C. D., and T. J. Ward. 1981. Principles of Aquatic Hazard evaluation as Applied to Ocean-Disposed Wastes. In: Aquatic Toxicology and Hazard Assessment: Fourth Conference, ASTM STP 737, D. R. Branson and K. L. Dickson, eds. American Society for Testing and Materials. pp. 138-158.

"The effects-based criteria identified in the 1977 ocean dumping regulations and associated guidelines for evaluating potential hazard of ocean-disposed wastes to aquatic organisms are reviewed. The use of these criteria, which provide for bioassay-based limiting permissible concentrations for physical phases of wastes to be compared with estimated environmental concentrations of the phases, is demonstrated in case studies of two wastes (acid-iron wastewater and dredged material) that are dumped in the ocean and one waste (formation water) that is discharged from an ocean outfall. The case studies present Lagrangian (exposure-time-dependent) assessments of the potential hazard of ocean-disposed wastes to plankton, as well as Eulerian (exposure-time-independent) evaluations of the potential hazard to nonplanktonic organisms. A plume study and models of different levels of sophistication are employed to estimate environmental concentrations of ocean-disposed materials" (author abstract)

78. Rubinstein, N. I., C. N. Asaro, and C. Sommers. The Effects of Contaminated Sediments on Representative Estuarine Species and Developing Benthic Communities. In: Contaminants and Sediments, Vol. 1, R. A. Baker, Ed. Ann Arbor Science, Ann Arbor, Michigan. pp. 445-461.

Laboratory studies were conducted using 10-gal aquaria receiving unfiltered sea water in a flow-through system. Tests were conducted for 28 days and measurements were made of survival of mysids, shell deposition and bioaccumulation of known contaminants by oysters, substrate reworking and bioaccumulation by lugworms, and the resiliency of the benthic community in terms of numbers and variety of macrofaunal organisms that settled onto test sediments from planktonic larvae within the exposure period. Sediments containing kepone were used and effects including mortality, decreased shell growth, decreased sediment reworking, and less colonization of kepone containing sediments were observed. Oysters and lugworms accumulated kepone. The author concluded that "Introduction of this material into the marine environment, even at the lowest concentration, could have an adverse impact on marine biota at the disposal site."

79. Rubinstein, N. I., E. Lores, N. R. Gregory. 1983. Accumulation of PCBs, Mercury and Cadmium by Nereis virens, Mercenaria mercenaria and Palaemonetes pugio from contaminated harbor sediments. Aquatic Toxicology. In Press.

"Accumulation of polychlorinated biphenyls (PCBs), mercury, and cadmium by sandworms (Nereis virens), hard clams (Mercenaria mercenaria), and grass shrimp (Palaemonetes pugio) exposed to contaminated sediments from four sites in New York Harbor was studied for a 100-day period. Of the three contaminants monitored, only PCBs were found to bioaccumulate above background (control) concentrations. Small increases in PCB body burden were detected in M. mercenaria and P. pugio, whereas higher concentrations were measured in N. virens. Uptake was affected by the organic content of the sediment. Bioaccumulation factors (concentration in tissue/concentration in sediment) for N. virens ranged from 1.59 in a low organic sediment to 0.15 in a high organic sediment. Results from this study support the contention that sediment concentration alone does not reflect bioavailability and that toxicity tests (bioassays) and field monitoring remain the most direct method for estimating bioaccumulation potential of sediment-bound contaminants." (author abstract)

80. Schiemer, E. W., J. R. Schubel, and G. M. Schmidt. 1971. A Laboratory Apparatus for Maintaining Uniform Suspensions of Fine-Grained Sediment. Tech. Rep. 70, Chesapeake Bay Institute, The John Hopkins University, Baltimore, Maryland. 9 pp.

The system described in this paper was designed to measure the effects of suspended sediments on fish eggs. The system employed a vertically-reciprocating, horizontal plate with an intermittent flow of the sediment slurry through the exposure tanks. No data were provided to substantiate the performance of the system when eggs were hatched in the suspension.

81. Schubel, J. R., A. H. Auld, and G. M. Schmidt. 1974. Effects of Suspended Sediment on the Development and Hatching Success of Yellow Perch and Striped Bass Eggs. Spec. Rep. 35, Chesapeake Bay Institute, March 1974. 12 pp.

A laboratory study was conducted to evaluate the effects of resuspended sediments on hatching success of yellow perch and striped bass eggs. Fine grained sediments collected from Chesapeake Bay were resuspended mechanically before intermittent introduction into aquaria holding eggs. Suspended solid concentrations of 50,100 and 500 mg/l had no effect on hatching success, while 1000 mg/l significantly reduced success. The authors stated that the highest concentration tested rarely occurred in nature, even in areas of dredging activity.

82. Schubel, J. R., and J. C. S. Wang. 1973. The Effects of Suspended Sediment on the Hatching Success of Perca flavescens (Yellow Perch), Morone americana (White Perch), Morone saxatilis (Striped Bass), and Alosa pseudoharengus (Alewife) Eggs. Spec. Rep. 30, Reference 73-3, Chesapeake Bay Institute, January 1973. 77 pp.

This laboratory study revealed that suspended sediment concentrations of up to 500 mg/l had no significant effect on hatching success of these four species. Sediments were collected from upper Chesapeake Bay; however, no contaminant analyses were performed on any samples.

83. Seelye, J. G., R. J. Hesselberg, and M. J. Mac. 1982. Accumulation by Fish of Contaminants Released from Dredged Sediments. Environ. Sci. and Technol., 16(8):459-464.

"Inasmuch as the process of dredging and disposing of dredged materials causes a resuspension of these materials and an increase in bioavailability of associated contaminants, we conducted a series of experiments to examine the potential accumulation by fish of contaminants from suspended sediments. In the first experiment we compared accumulation of contaminants by yellow perch of hatchery and lake origin and found that after 10 days of exposure to non-aerated sediments, fish of hatchery origin accumulated PCBs and Fe, while fish of lake origin accumulated As, Cr, Fe, and Na. Two additional exposures were conducted to evaluate the effects of aerating the sediments prior to measuring bioavailability of associated contaminants. Fish of hatchery origin exposed to non-aerated sediments for 10 days accumulated PCBs and Hg, while fish of hatchery origin exposed to aerated sediments for 10 days accumulated PCBs, DDE, Zn, Fe, Cs, and Se. These results not only demonstrated the potential for uptake of contaminants by fish as a result of dredging, but also the potential utility of fish bioassays in evaluating proposed dredging operations." (author abstract)

84. Sherk, J. A., Jr., and L. E. Cronin. 1970. The Effects of Suspended and Deposited Sediments on Estuarine Organisms. Reference No. 70-19, University of Maryland Natural Resources Institute. 61 pp.

This literature review on sediment effects in estuaries contains over 40 references related to dredging activities. The review concentrated on coastal engineering projects and the authors concluded that little information was available on biological effects.

85. Sherwood, M. J. 1976. Fin Erosion Disease Induced in the Laboratory. 1976. In: Coastal Water Research Project Annual Report, 1976, Southern California Coastal Water Research Project, El Segundo, California. pp. 149-153.

Dover sole (Microstomus pacificus) were held in the laboratory for 13 months over either contaminated sediments collected from the Palos Verdes (California) shelf, or over silica sand. The Palos Verdes sediments were characterized by high concentrations (mg/dry kg) of DDT (120), PCBs (5.0), and metals. Fish held in tanks with contaminated sediment showed early signs in fish erosion as well as elevated levels of DDT and PCBs, compared to control fish.

86. Shin, E. B., and P. A. Krenkel. 1976. Mercury Uptake by Fish and Biomethylation Mechanisms. J. Water Pollut. Control Fed., 48(3):473-501.

A series of laboratory exposures of Poecilia reticulatus and Gambusia affinis to artificial sediments spiked with $HgCl_2$ or HgS were conducted to examine the effects of various environmental conditions on methylmercury uptake. Factors that enhanced methylmercury uptake by fish included: use of $HgCl_2$ rather than HgS, higher water temperature, Cl^- ion concentration in water of 200 mg/l, and higher sediment concentrations of mercury. Other factors affecting uptake were sediment microorganism density, sorption characteristics of sediment and form of mercury present.

87. Shuba, P. J., J. H. Carroll, and H. E. Tatem. 1976. Bioassessment of the Standard Elutriate Test. Misc. Pap. D-76-7, U.S. Army Engineers Waterways Experiment Station, Vicksburg, Mississippi. 29 pp.

Laboratory studies were conducted with algae, bacteria and protozoans exposed to elutriate water. Tests were run for 8 to 14 days under static conditions. The authors concluded that the algal assay procedure was a useful method, but the results of the bacteria and protozoa assays were too variable to be useful.

88. Shuba, P. J., J. H. Carroll, and K. L. Wong. 1977. Biological Assessment of the Soluble Fraction of the Standard Elutriate Test. Tech. Rep. D-77-3, U.S. Army Engineers Waterways Experiment Station, Vicksburg, Mississippi. 109 pp.

Laboratory studies were conducted using sediments from Ashtabula, Ohio; Galveston, Texas; and Mobile, Alabama. The tests conducted included bioassays using algae, bacteria and protozoans with measurements of biomass change or respiration. Only metals and nutrients were measured in the elutriate test. Static tests with appropriate dilutions of

elutriate water were used, lasting from 8 to 18 days. The algae did not respond to elutriate waters, while the response of bacteria and protozoa was not predictable.

89. Shuba, P. J., S. R. Petrocelli, and R. E. Bentley. 1981. Considerations in Selecting Bioassay Organisms for Determining the Potential Environmental Impact of Dredged Material. Tech. Rep. EL-81-8, U.S. Army Engineers Waterways Experiment Station, Vicksburg, Mississippi. 94 pp.

The report presents the following factors for consideration in selecting bioassay organisms:

1. The organism if found at the disposal site.
2. The organism is readily available through field collecting or purchasing.
3. A toxicological data base exists for the organisms.
4. Response to the same toxicant is reproducible.
5. The organism can be maintained in a healthy condition in the laboratory.
6. The organism can be cultured and will reproduce under laboratory conditions.
7. The organism can be used in major types of bioassays.
8. The organism occurs over a wide geographic area.
9. The organism is economically or ecologically important.
10. The organism is compatible with other test species.

The authors present a literature review on a number of topics relative to biological testing of sediment quality.

90. Shuba, P. J., H. E. Tatem, and J. H. Carroll. 1978. Biological Assessment Methods to Predict the Impact of Open-Water Disposal of Dredged Material. Tech. Rep. D-78-50, U.S. Army Engineers Waterways Experiment Station, Vicksburg, Mississippi. 162 pp.

Laboratory toxicity and growth tests were conducted with a variety of benthic or planktonic invertebrates. Toxicity tests were conducted for 96 hours, while growth studies were run for 33 days. All tests were conducted under static conditions. Results varied depending on the level of contaminants in the sediments, the sensitivity of the test organism, and the duration of the exposure. Clams and shrimp were exposed to PCB contaminated sediments and both showed significant accumulation of PCBs after 14 days.

91. Slotta, L. S. 1973. Dredging Problems and Complications. In: Coastal Zone Management Problems, Oregon State University, January 1974. pp. 39-52.

A brief literature review on dredging effects with emphasis on estuarine ecosystems. Little information is presented on effects of contaminated sediments.

92. Southworth, G. R., B. R. Parkhurst, and J. J. Beauchamp. 1979. Accumulation of Acridine from Water, Food, and Sediment by the Fathead Minnow Pimephales promelas. Water Air Soil Pollut., 12:331-341.

Fathead minnows were exposed in the laboratory to sediments containing acridine, a synthetic fuel by-product. Minnows were exposed to sediments containing 113 ± 4 µg/g acridine (dry) for 107 days. Water concentration of acridine equilibrated at about 10 µg/l. Fish concentrated acridine to 1.4 µg/g for a concentration factor (based on water concentration) of 139.5. This was equal to concentration factors found at higher water concentrations without sediment.

93. Stout, V. F., and L. G. Lewis. 1977. Aquatic Disposal Field Investigations, Duwamish Waterway Disposal Site, Puget Sound, Washington, Appendix B: Role of Disposal of PCB-Contaminated Sediment in the Accumulation of PCB's by Marine Animals. Tech. Rep. D-77-24, U.S. Army Engineers Waterways Experiment Station, Vicksburg, Mississippi, November 1977. 77 pp.

A field study was conducted to examine PCB uptake by aquatic organisms at a dredge disposal site. Indigenous animals, English sole (Paraphrys vetulus) and pink shrimp (Pandolus borealis and P. jordani) analyzed for PCBs before and after the disposal were not found to be affected by the disposal. Additional animals were caged at the disposal site and analyzed for PCBs: spot shrimp (P. platyceros), sea cucumber (Parastichopus californicus), and mussel (Mytilus edulis). Only mussels showed a small increase in PCB concentration during disposal and the authors concluded that no obvious changes in PCB levels were occurring in Elliot Bay organisms. Initial PCB concentrations in the organisms were relatively high, however, and the PCB influx from the Duwamish River may well have masked possible bioaccumulation at the disposal site.

94. Swartz, R. C., W. A. DeBen, and F. A. Cole. 1979. A Bioassay for the Toxicity of Sediment to Marine Macrobenthos. J. Water Pollut. Control Fed., 51(5):944-950.

Laboratory toxicity tests were conducted with sediments from 9 areas and with 5 marine benthic macroinvertebrates. Organisms were acclimated to control sediments, then covered with a layer of the test sediment. A continuous flow of seawater was maintained except during a one-hour period right after the test sediments were added. All tests were conducted for 10 days as required in the "Ocean Dumping Implementation Manual." Effects of burial were minimal, with all organisms showing less than 10% mortality due to burial with no substantial differences in mortality between depths of burial. The results of toxicity tests appear quite precise; however, no relationship was measured between toxicity and contaminants present.

95. Sweeney, R. A. 1978. Aquatic Disposal Field Investigations, Ashtabula River Disposal Site, Ohio, Appendix A: Planktonic Communities, Benthic Assemblages, and Fishery. Tech. Rep. D-77-42, U.S. Army Engineers Waterways Experiment Station, Vicksburg, Mississippi. 330 pp.

Gillnets and fathometric surveys were used to determine relative abundance of fish at nearshore and offshore areas. Pre- and post-larval disposal surveys were conducted. Effects on adult fish ranged from slight avoidance of the initial disposal to migrating actively from the site but returning within 15 min. No long-term effects were noted.

96. Tatem, H. E. 1980. Exposure of Benthic and Epibenthic Estuarine Animals to Mercury and Contaminated Sediment. Contaminants and Sediments, Vol. 1, R. A. Baker, eds. Ann Arbor Science, Ann Arbor, Michigan. pp. 537-549.

Laboratory tests were conducted using organisms collected along the Gulf Coast. Test sediments were collected along the Houston Ship Channel and other Gulf Coast locations. Exposures of organisms were performed under static conditions for 8-25 days. Mortality was measured under a variety of exposure conditions, including exposures of organisms to dissolved mercury with sediments present, and exposure of organisms to sediments with high metals and organic contaminants. Results of these exposures demonstrate high variability of bioassay results.

97. Titus, J. A., J. E. Parsons, and R. M. Pfister. 1980. Translocation of Mercury and Microbial Adaptation in a Model Aquatic System. Bull. Environ. Contam. and Toxicol., 25:456-464.

In a model ecosystem, sediments were spiked with a 1 g lobule of metallic mercury. Sediment, plankton, gastropods, and goldfish were analyzed to follow movement of mercury in the system. Mercury had moved through all sediments in 7 weeks, and had equilibrated in water after 12 weeks. Detectable levels of mercury were found in plankton after 10 weeks. During weeks 12 through 40, Hg in snails and goldfish accumulated concentrations up to 1000 times that in water.

98. Trefry, J. H., R. R. Sims, Jr., and B. J. Presley. 1976. The Effects of Shell Dredging on Heavy Metal Concentrations in San Antonio Bay. In: Shell Dredging and Its Influence on Gulf Coast Environments, A. H. Bouma, ed. Gulf Publishing Co., Houston, Texas. pp. 161-184.

Sediments, water, and aquatic organisms were collected from dredged and undredged areas of San Antonio Bay (Texas) and analyzed for heavy metals. Although no samples were collected during a dredging activity, the authors concluded that dredging had no effect on metal availability to organisms. This conclusion was based on the fact that metal levels in all samples from dredged areas were relatively low compared to undredged areas.

99. Trident Engineering Associates, Inc. 1977. Evaluation of the Problem Posed by In-Place Pollutants in Baltimore Harbor and Recommendation of Corrective Action. EPA 440/5-77-015B, U.S. Environmental Protection Agency, Office of Water Planning and Standards. 77 pp.

Laboratory toxicity tests were run using 2 species of fish and a species of clam. Static tests were conducted using a small pump to mix water and sediment in the tanks. Organisms were screened from contact with bedded sediment. Tests were run for 48 h with fish and for 96 h with clams. Bioassay results were significantly correlated with bulk measurements of metals, PCBs, and hexane extractables. A definite dose response was measured with the initial effects attributed to chemicals present, followed by physical effects adding to the chemical effects after a certain point.

100. U.S. Environmental Protection Agency. 1976. Bioassay Procedures for the Ocean Disposal Permit Program. Environmental Research Laboratory, Gulf Breeze-Narragansett-Corvallis. 96 pp.

Nine laboratory procedures are described for testing the toxicity of waste materials considered for ocean disposal. Both static and flow-through tests are included. The methods cover the use of a range of trophic levels as test organisms from algae to fish. Six of the procedures are for acute toxicity measurements and the other three are termed "special" or chronic studies that are not recommended for routine use. None of the methods was designed for measuring bioaccumulation.

101. U.S. Environmental Protection Agency/Corps of Engineers Technical Committee on Criteria for Dredged and Fill Material. Ecological Evaluation of Proposed Discharge of Dredged Material into Ocean Waters; Implementation Manual for Section 103 of Public Law 92-532 (Marine Protection, Research, and Sanctuaries Act of 1972). July 1977 (Second Printing April 1978), Environmental Effects Laboratory, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

This manual provides summaries and discussions of the procedures for evaluation of dredged material prior to disposal in the ocean, as required by the Federal Register. A general approach section consists of rationale behind the technical evaluation process which includes tests of liquid phase, suspended particulate phase, solid phase, bioaccumulation, initial mixing, trace contaminants, and compatibility with disposal site. Appendices in the manual provide detailed methods for the various tests.

102. Varanasi, U., and D. J. Gmur. 1981. Hydrocarbons and Metabolites in English Sole (Paraphrys vetulus) Exposed Simultaneously to ^{3}H Benzo[a]Pyrene and ^{14}C Naphthalene in Oil-Contaminated Sediment. Aquat. Toxicol., 1:49-67.

Sediments artificially oiled with radioactive benzo[a]pyrene and naphthalene in Prudhoe Bay crude oil were placed in tanks with English sole in the laboratory. After 24- and 168-h exposures, both compounds were present in tissues and major organs. Naphthalene was taken up to a greater extent than benzo[a]pyrene, although naphthalene concentrations decreased in many organs between 24 and 168 h. Benzo[a]pyrene was metabolized to a great extent in sole tissue.

103. Wentsel, R., A. McIntosh, and V. Anderson. 1977. Sediment Contamination and Benthic Macroinvertebrate Distribution in a Metal Impacted Lake. Environ. Pollut., 14(3):187-193.

Samples of sediment and benthic invertebrates were collected from five sites in a eutrophic lake in Indiana. Numbers and species of invertebrates were enumerated and sediments analyzed for Cd, Zn, and Cr. Two sites near an industrial effluent had extremely high concentrations of all three metals and were also characterized by large numbers of Limnodrilus sp. and very few chironomids. The other three sites became progressively lower in metal concentrations as they increased in distance from the point source and also exhibited decreasing numbers of Limnodrilus and increasing numbers of chironomids.

104. Wright, T. D. 1978. Aquatic Dredged Material Disposal Impacts. Tech. Rep. DS-78-1, U.S. Army Engineers Waterways Experiment Station, Vicksburg, Mississippi, August 1978. 57 pp.

A summary of the findings obtained from field investigations of five aquatic disposal projects. The author points out the site-specificity of impacts, implying that results are not conclusive for all cases. Releases of some toxic substances were measured (PCBs, manganese, ammonia); however, no bioaccumulation was measured. No toxic effects were measured, but the author stated that they could not be ruled out.

105. Wyeth, R. K., and R. A. Sweeney. 1978. Aquatic Disposal Field Investigations, Ashtabula River Disposal Site, Ohio, Appendix C: Investigation of Water Quality and Sediment Parameters. Tech. Rep. D-77-42, U.S. Army Engineers Waterways Experiment Station, Vicksburg, Mississippi, July 1978. 344 pp.

A field study was conducted to evaluate the effects of a disposal operation in Lake Erie off Ashtabula, Ohio. Oligochaeta and fish were analyzed for trace metals before and after disposal. Benthos exhibited no increase in metals; however, fish showed accumulation of all metals, especially Fe, Cd, Ni, and Mn. The magnitude of the increase was correlated with concentrations in sediment. The authors also reported some unreliability of elutriate test data.

106. Yockim, R. S., A. R. Isensee, and G. E. Jones. 1978. Distribution and Toxicity of TCDD and 2,4,5-T in an Aquatic Model Ecosystem. Chemosphere, 3:215-220.

Artificial silt loam soil was treated with ^{14}C-TCDD (0.1 µg/g) or ^{14}C-2,4,5-T (0.1, 1.0, or 10.0 µg/g) and placed in a recirculating ecosystem. Daphnia magna, snails (Helosoma sp.), algae (Oedogonium cardiacum), and fish (Gambusia affinis) were added to the ecosystem and sampled periodically from 1-32 days after introduction. Bioaccumulation ratios (tissue concentration/water concentration) of 2-6 x 10^3 were measured for organisms exposed to TCDD and <50 for organisms exposed to 2,4,5-T. High mortality to G. affinis was observed in the TCDD system.

APPENDIX B

Accumulation:

Chlorinated hydrocarbons - 3, 16, 17, 20, 22, 32, 33, 34, 54, 59, 62, 64, 65, 66, 67, 68, 75, 78, 79, 83, 85, 90, 93, 101, 106

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15. SUPPLEMENTARY NOTES
Anthony Kizlauskas
Project Officer

16. ABSTRACT

A literature review of sediment bioassessment was conducted as the first step in the development of a more standardized and ecologically sound test procedure for evaluating sediment quality. Based on the review, the authors concluded that 1)a standardized laboratory bioassessment test should consistof flow-through exposure of at least 10 days duration using more than one aquatic organism including at least an infaunal benthic invertebrate and a fish species. 2) Before adoption of a laboratory sediment bioassessment procedure, the laboratory results should be evaluated by comparison with field conditions. 3) Most current sediment bioassessment regulatory tests measure acute toxicity or bioaccumulation. Development of tests to evaluate chronic, sublethal effects is needed.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Bioavailability of metals Bioassessment test Inorganic contaminants Ecosystem Aquatic organisms Toxic Substances Sediments Dredging		

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